Excerpt from April 2005 Fermilab Physics Advisory Committee Recommendations

NOνA (P-929)

The recent discovery of neutrino mass and mixing has revealed exciting questions about neutrinos and their connections to other areas of physics and astrophysics The multi-divisional neutrino study of the American Physical Society has identified these questions. The NOνA experiment, and further steps to which it might logically lead, could make a unique and very important contribution to answering them.

The APS study has advocated a comprehensive U.S. program to complete our understanding of neutrino mixing, determine the neutrino mass hierarchy, and search for CP violation in the neutrino sector. The character of the hierarchy will provide evidence concerning grand unification, and neutrino CP violation might be the key to understanding the matter-antimatter asymmetry of the universe. NOνA is an important step in the recommended U.S. program. In the near term, NOνA shows promise to be the world's most sensitive probe of θ_{13}, a critical mixing angle on which CP violation depends, and NOνA has the unique opportunity to determine the neutrino mass hierarchy, depending on the values of θ_{13} and the CP-violating phase δ. In case θ_{13} is too small for NOνA to determine the hierarchy, an extension of NOνA, with a significantly upgraded neutrino beam intensity and/or additional detectors, offers the unique opportunity to determine the hierarchy as long as $\sin^2 2\theta_{13} > 0.02$, and could also establish the presence of CP violation in neutrino oscillation for a wide variety of values of θ_{13} and δ. Because of its longer baseline, NOνA is more sensitive to matter effects than the Japanese experiment T2K, making the two experiments complementary. Combining results from NOνA and T2K will distinguish CP-violating effects from matter effects in the asymmetry between neutrino and anti-neutrino oscillations. Likewise, NOνA and reactor neutrino experiments are complementary. Reactor experiments are completely insensitive to the mass hierarchy and CP violation, but by providing a measurement of θ_{13} that is free of uncertainties due to either of these effects, they will facilitate NOνA's study of them. Additional discussion of the physics behind NOνA may be found in the report of the June 2004 PAC meeting.

Developments since Committee discussions of NOνA last year have strengthened the scientific case for NOνA. New projections of available proton flux improve the experiment's sensitivity, and the DOE budget request for FY06 makes timely construction feasible. In the post-Collider era, a proton flux of 6.5×10^{20} protons on target per year is planned, an increase of 91% relative to projections a year ago. This flux will improve the sensitivity of NOνA, increasing the range of delta over which a five-year NOνA run is more sensitive to $\sin^2 2\theta_{13}$ than T2K Phase 1 or a "medium-scale" reactor experiment, making NOνA more sensitive over the full range of delta for the normal mass hierarchy. Within the DOE FY06 budget request, NOνA R&D can be supported in FY06, construction of NOνA could commence as early as FY07, and initial operation of a partial detector could commence as early as FY10. The Committee is pleased by these developments. It would also like to reiterate the desirability of timely initiation of the NOνA construction project and operation.

The NOνA collaboration has completed the steps requested at the June 2004 PAC meeting. It has finalized the choice of detector design, mass, and location. In particular, the collaboration has chosen a Totally Active Scintillator Design as its baseline detector technology. The Committee supports this choice and is impressed by the progress in the ongoing engineering studies of this design. The collaboration has also measured the photo-electron yield for a full-length cell. They have continued studies of cosmic ray backgrounds, and have further investigated scenarios that enable a rapid initial start with a partial detector. The collaboration has updated its proposal to reflect the full scientific case.

The Committee finds that: (1) the neutrino physics to be addressed by NOνA is compelling; (2) NOνA will be competitive with other experiments that will or may operate in the same time frame, and it will be complementary to those experiments in furthering understanding of neutrino physics; (3) NOνA is well-optimized for its physics goals; and (4) NOνA will provide a sound basis for future experimental extensions. The Committee recommends Stage I approval of NOνA.

Before construction approval, NOνA will be subjected to review by external advisory groups. In order to help the Collaboration to prepare for these reviews, the Committee recommends consideration of the following points, with quantitative answers to questions where appropriate. The Committee looks forward to further information on these points before the June PAC meeting.

- Plans for a future Proton Driver at Fermilab may be affected if the ILC is sited here. Please describe, in the context of the worldwide neutrino program, how the future program of NOνA might evolve in the absence of a proton driver at Fermilab. In that case, what will be the best evolution of NOνA in order to continue to resolve determination of $\sin^2 2\theta_{13}$, the mass hierarchy, and CP violation? Show the sensitivity of NOνA, individually and combined with other possible experiments, in the preferred scenario(s).
- The NOνA Far Detector is a large, novel structure. Structural issues associated with the proposed glued PVC design are undergoing careful analysis by the NOνA team. Consider building an appropriate mechanical prototype of a section of the detector at an early stage to add confidence to the design. What safety or environmental concerns may arise due to the novel structure? What approvals will be necessary, and what will be their impact on cost and schedule?
- NOνA specifies a requirement of 25 photo-electrons for a minimum ionizing particle at the far-end from the avalanche photodiodes. Present prototype results allow extrapolation to yields that meet this requirement. Prototypes with actual cell and fiber diameters and lengths should be used to validate these extrapolations as soon as possible.
- The Committee encourages NOνA to perform more complete studies of the various sources of background to be expected in the Far Detector, including addressing the following points:
    - A more detailed evaluation of the cosmic ray background is necessary in order to assess whether or not the detector needs an overburden. This study has

implications on the construction of the far site and should be completed in a timely manner.

- NOνA plans to minimize the mismatches between the neutrino spectra in the Near and Far Detectors in two ways: by taking data at various sites in the NuMI tunnel and by using Monte Carlo predictions to extrapolate from the Near Detector to the Far Detector. What are the practical implications of moving the Near Detector? How do the MC predictions rely on hadron and neutrino cross-section measurements performed by other experiments, such as MIPP and MINERνA?

- The Committee encourages NOνA to perform more complete full-simulation studies of the expected detector performance, addressing in particular the energy reconstruction accuracy as a function of the incoming neutrino energy, down to the lowest relevant energies.
- How could the results of a "medium-scale" reactor neutrino experiment be used with results from NOνA, and from NOνA and T2K, in order to improve the combined sensitivity? If a contemporaneous medium-scale reactor experiment exists, how could the NOνA run program be adapted to provide the best combined sensitivity?
- Plots in the NOνA proposal assume 6.5×10^{20} pot/year. Please plot sensitivity for a more conservative flux of 4.9×10^{20} pot/year, or show bands of sensitivity for a range of proton fluxes.
- Please plot a direct comparison of the sensitivity of NOνA in the Proton Driver era with a high-intensity JPARC program, with and without a larger detector such as HyperK.